Visualization and Beyond

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Visualization has made considerable impact in different sub-fields of science, engineering and medicine. Today visualization is an integral part of multi-billion dollar industry, including CAD/CAM, medical imaging, entertainment, high-performance computing, etc. Visualization is now routinely used in design and manufacturing of man-made structures including architectural models, aircrafts, automobiles, power-plants, submarines, tankers, space vehicles, etc. Another application area is training and education, such as flight simulation, emergency personnel training, surgical simulators, mission rehearsal, strategic planning, electronic instruction, etc. It is also heavily used in scientific visualization to analyze and understand complex datasets, and in health care from medical imaging, procedural simulators, to image-guided surgery.

Visualization is considered as a mean of displaying information (virtual, simulated, or real) and also a form of human computer interaction. Interaction requires two-way communication: (1) means to acquire the data and track changes as they occur; (2) ways to understand and analyze (e.g. cluster, partition, interpolate) the data, process (e.g. extrapolate, simulate, annotate) information, and communicate the results (e.g. via graphical, haptic, or auditory display) back to the user.

The current visualization techniques are either limited to relatively simple models or datasets (in terms of *computational scale*, *combinatorial complexity*, and *problem scope*) or cannot perform real-time computations on complex, heterogeneous scenes or dynamically evolving data. In addition, the existing human system interaction is limited and often unnatural, which makes data analysis and product testing difficult and cumbersome. These limitations in turn hinder the applications of visualization to broader domains. Based on the existing problems we are facing, the following research areas can potentially help lifting visualization today to the next level:

Computational Methodologies

- We need to develop scalable algorithms, simulation techniques and numerical methods that can handle complex data and their interaction (e.g. between heterogeneous materials, among numerous entities, with perhaps changing geometry, topology and physical conditions). Techniques, such as ***multiresolution*** algorithms and ***multi-scale*** methods, often developed in applied mathematics and scientific computation, are designed to target some of these problems. However, we need to be able to adapt them intelligently for different visualization applications.
- Some organizations and institutes have access to computational grids and high-performance computing resources, but unfortunately the larger community does not have such access. In addition, high-performance computing tools and environments often require special expertise to run applications. We need to consider "***desk-top***" or "***mobile***" ***high performance computing*** by exploiting SIMD capabilities on other cheaper alternatives, such as high-end commodity microprocessors and graphics processors that also have inherent "data-parallelism" that can be exploited to accelerate the computation.

Science of Integration

- Many existing visualization techniques are not readily applicable to ***massive*** datasets arising from complex engineering, physical, or biological systems. In addition, various rendering acceleration techniques or simulation methods use different data structures and numerical methods that do not integrate with each other well. Thus, a unified approach to display massive datasets and simulate complex, dynamic, heterogeneous systems, possibly at different scales, will need to be investigated. Furthermore, data management needs to taken into account, as it is an integral part of visualizing and analyzing massive datasets.
- The science of integration is perhaps the most challenging engineering issue. Semantics, ontology and standards will need to be defined, so that different components designed by different groups can be integrated together to form a larger system and different systems can be brought together to validate their interoperability among them in a larger environment (e.g. a nano-scale robot, a human system, a transportation system, a city under pollution or biochemical weapon attack, the national water system, the world's ecological environment, etc.)

Human-System Interaction

- Interaction is most realistic when it is generated based on what we expect, i.e. consistent with the behavior of the objects in the real world and compliant with the law of physics. Therefore, we need to consider developing true 3D interfaces that are ***physically-based***, subject to other design constraints and real-time performance requirements.
- Existing visual display can be augmented by ***haptic visualization*** to truly achieve *bi-directional* interface design. In addition, haptics provides a natural 3D interface that makes graphics tangible and allows the engineers and scientists to truly interact with the virtual or simulated system in a more natural and intuitive manner.

With a complete, end-to-end system, visualization technologies can be applied to various novel domains. The economic impact and the social implications can be tremendous. In addition to the research areas mentioned above, we also need to promote and accelerate the transition of visualization technology into the innovative real-world applications via some type of joint efforts that include academia, government, and industry. This objective can be encouraged by new program initiatives.